Simulation of Potential Enhancements in Parabolic Trough Solar Field Start-up Controllers using Nowcasting Systems

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Motivation

- It is challenging to estimate the performance of new components in an operational solar field.

Challenge/Opportunity	Possible solution
Investigate the opportunities that new technologies and components offer and their effect on the energy yield	Offer a **virtual** platform for reproducible tests without interrupting the operation
Losses due to transient processes during solar field start-up.	Develop novel **control** concepts
Nowcasting system provide highly spatially (5mx5m) & temporally (15 min.) discretized DNI maps with up to 15-min forecasts	Estimate and compare **economic** benefits in revenues

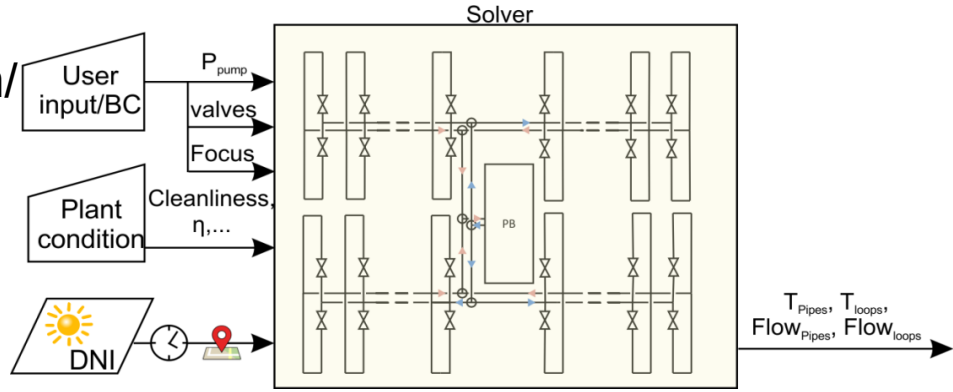
The Virtual Solar Field (VSF)

About:

An in-house **dynamic** simulation tool capable of representing a **complete solar field** in high level of detail using a **computationally efficient** implementation.

Main features:

- Compute flow distribution in the field according to pressure losses in each pipe.
- Flexible solar field layout and operation/ maintenance.
- Use spatially varying DNI.
- Add-on solar field and collector controllers.



Noureldin, K., Hirsch, T., and Pitz-Paal, R. “Virtual Solar Field – Validation of a detailed transient simulation tool for line focus STE fields with single phase heat transfer fluid”. In: Solar Energy 146 (2017)

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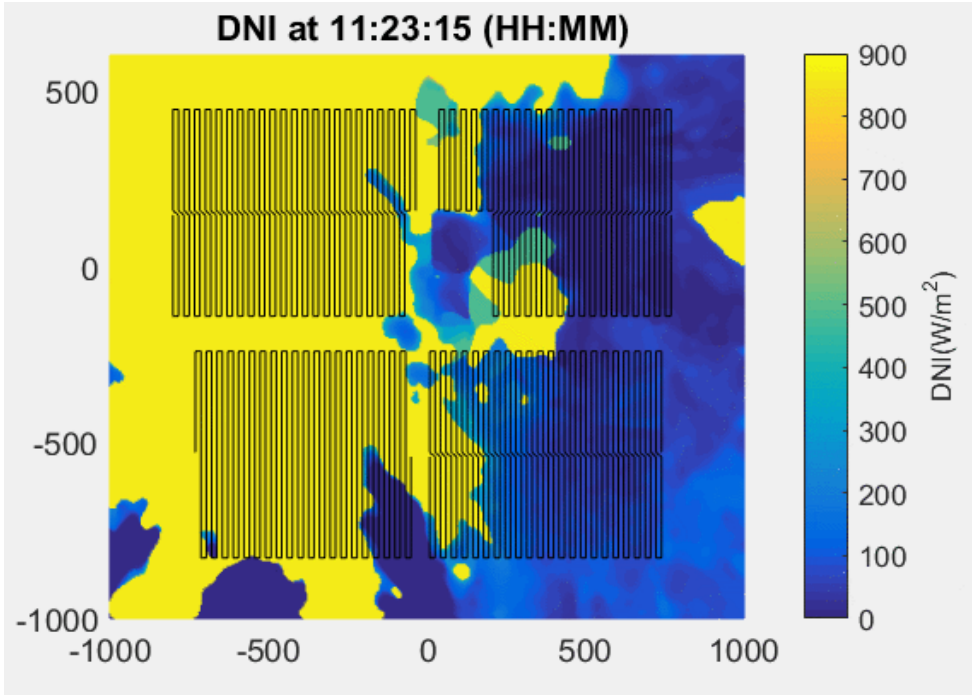
Nowcasting system

- Based on cloud cameras.
- Clouds are detected and shadows are projected to the ground.
- By calculating cloud motion vectors → short-term forecasts up to 15 minutes.



B. Nouri, P. Kuhn, S. Wilbert, C. Prahl, R. Pitz-Paal, P. Blanc, T. Schmidt, Z. Yasser, L. R. Santigosa, D. Heineman, “Nowcasting of DNI maps for the solar field based on voxel carving and individual 3D cloud objects from all sky images”, SolarPACES, Santiago, Chile, 2017.

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Reference start-up controller (Principle)

Operation mode

Anti-freeze

DNI_{avg} > 130 W/m²,
$\dot{m}_{req}$ > 0.9 kg/s/loop

Start-up

ΔT_{out} <= 15K

normOp

Reference start-up controller (Principle)

Operation mode	SCA controller	T grad FB	Flow FF	T controller
Anti-freeze	defocus	-	min. flow	-
⇩	DNI_{avg} > 130 W/m², $\dot{m}_{req}$ > 0.9 kg/s/loop			
Start-up	emergency defocus only	×	×	Flow recirculation till T_{out} > 335°C
⇩	ΔT_{out} <= 15K			
normOp	SCA T PI-control	-	×	×

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Challenge/Opportunity	Possible solution (?)
Investigate the opportunities that new technologies and components offer and their effect on the energy yield	Offer a **virtual** platform for reproducible tests without interrupting the operation ✓
Losses due to transient processes during solar field start-up.	Develop novel **control** concepts ✓
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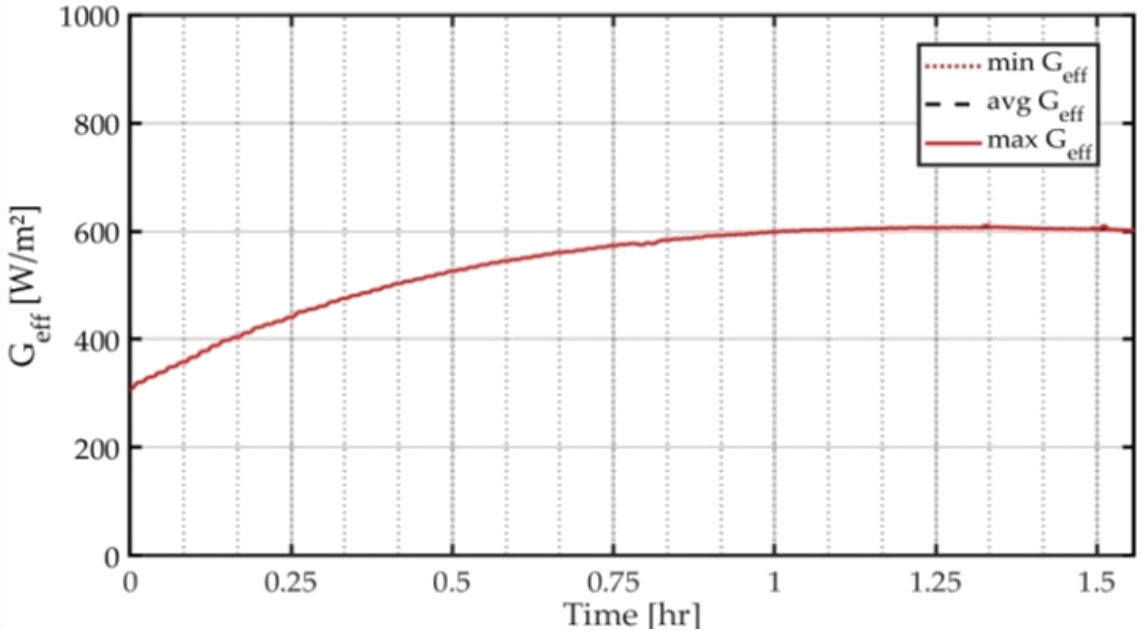
Reference start-up controller (Example)

- Simulation of La Africana near Córdoba, Spain
- 168 loops in 4 subfields. Thermal oil as HTF



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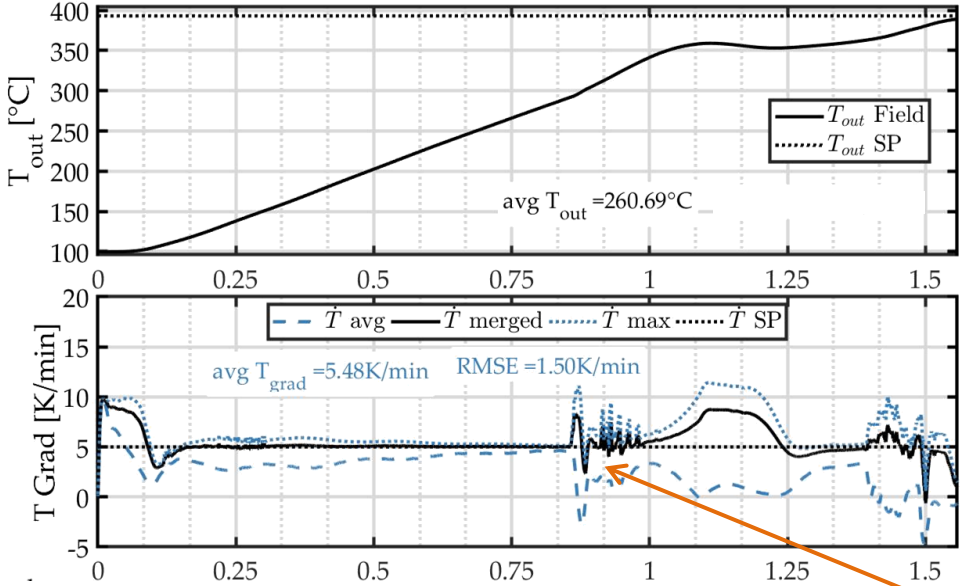
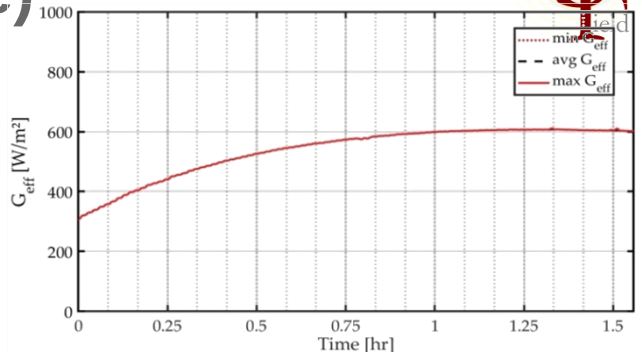




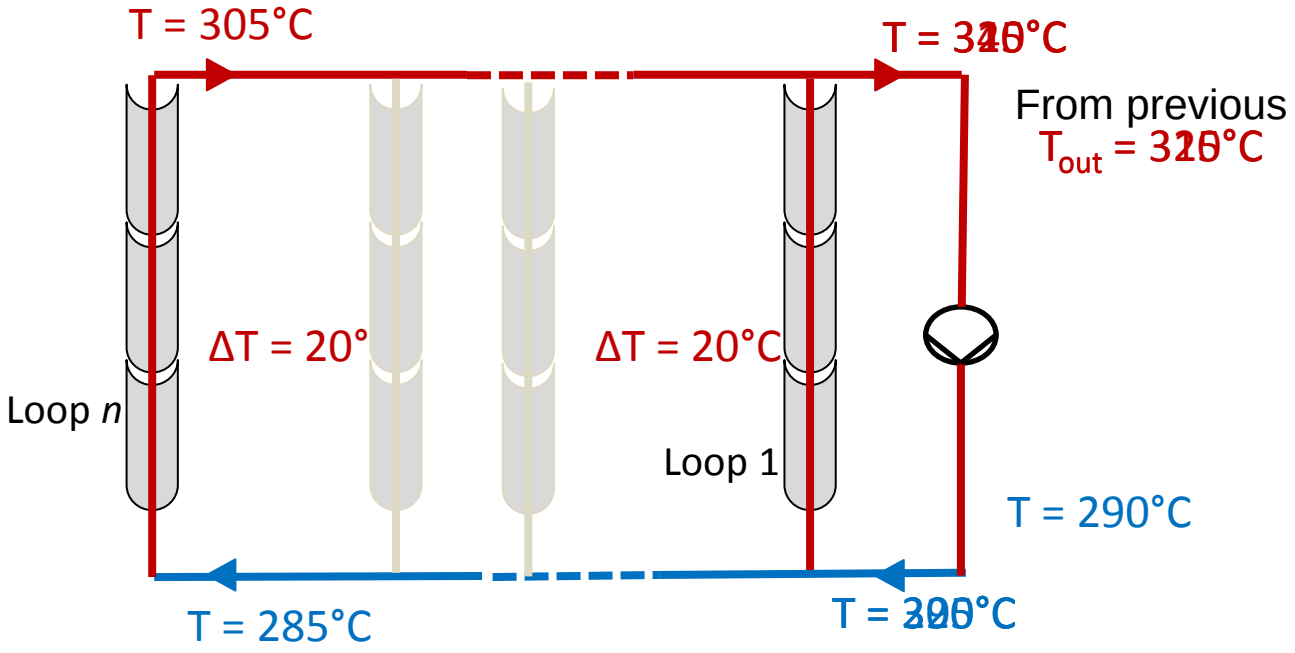
- Simulation of La Africana near Córdoba, Spain
- 168 loops in 4 subfields.

$$\dot{T}_{merged} = \frac{2.75\,\dot{T}_{max} + 1.25\,\dot{T}_{avg}}{4}$$

Disturbance due to a jump in inlet temperature after recirculation

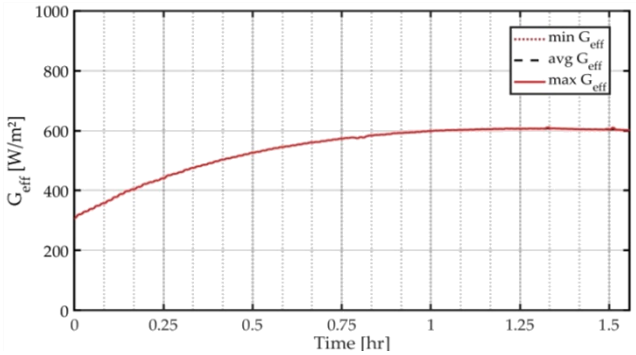
Temperature band in loops during recirculation

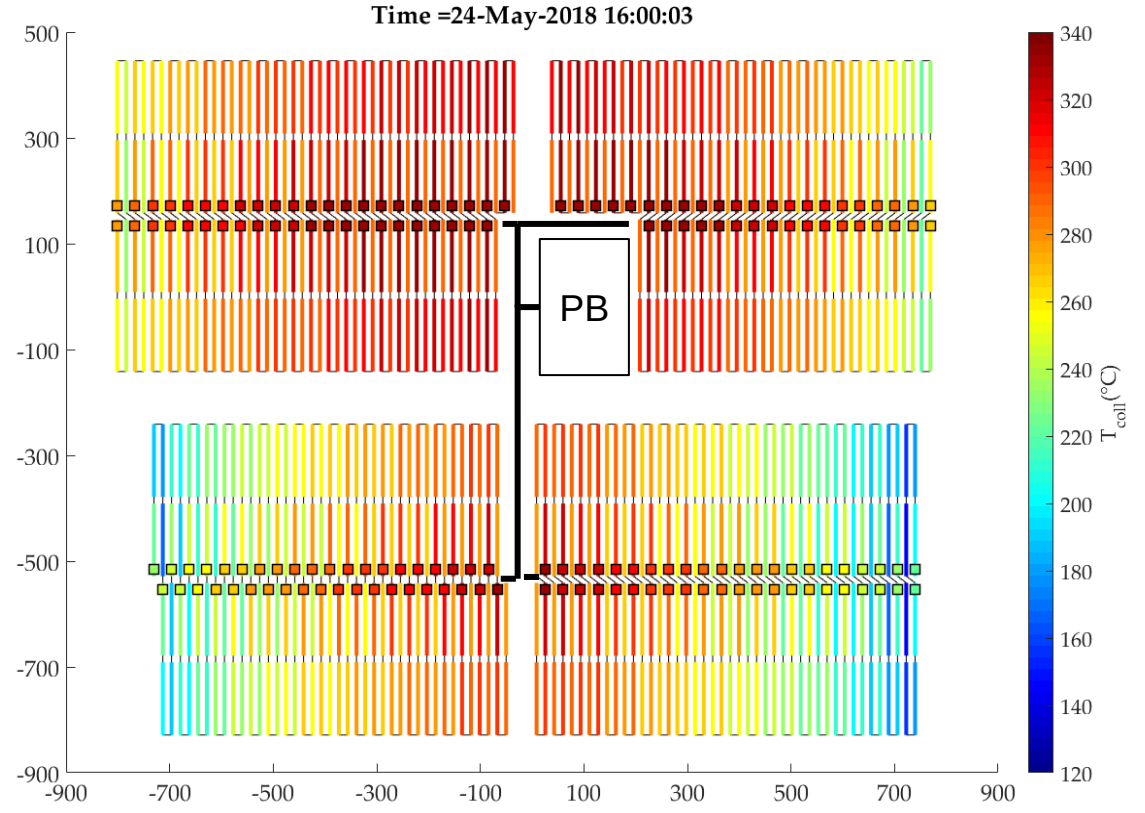
- Fluid travel time in header pipes results in varying inlet temperatures and loop temperature differences of up-to 50 K.



Loop temperatures during start-up

- Snap shot at t = 1.25 hr
- High variation in loop temperatures

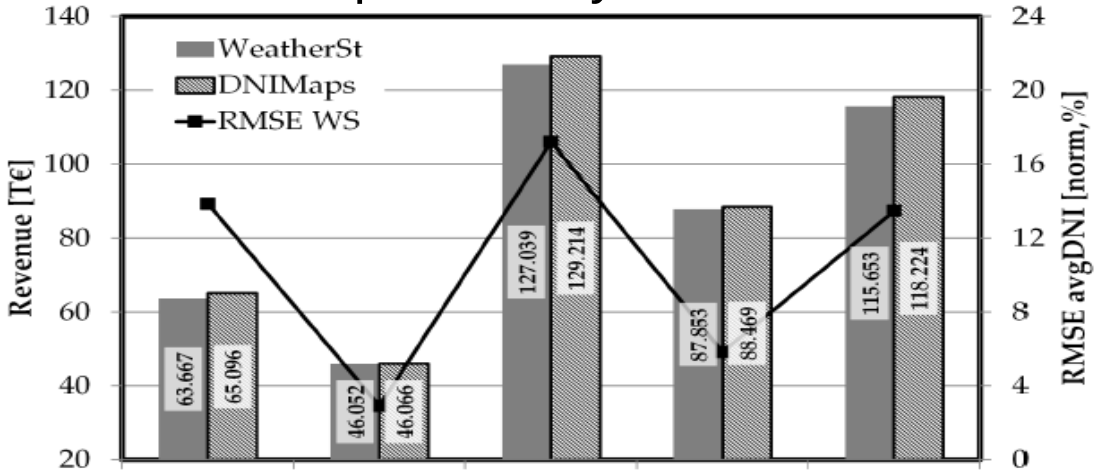




How can nowcasting help during start-up?

Benefit of nowcasting system in normal operation

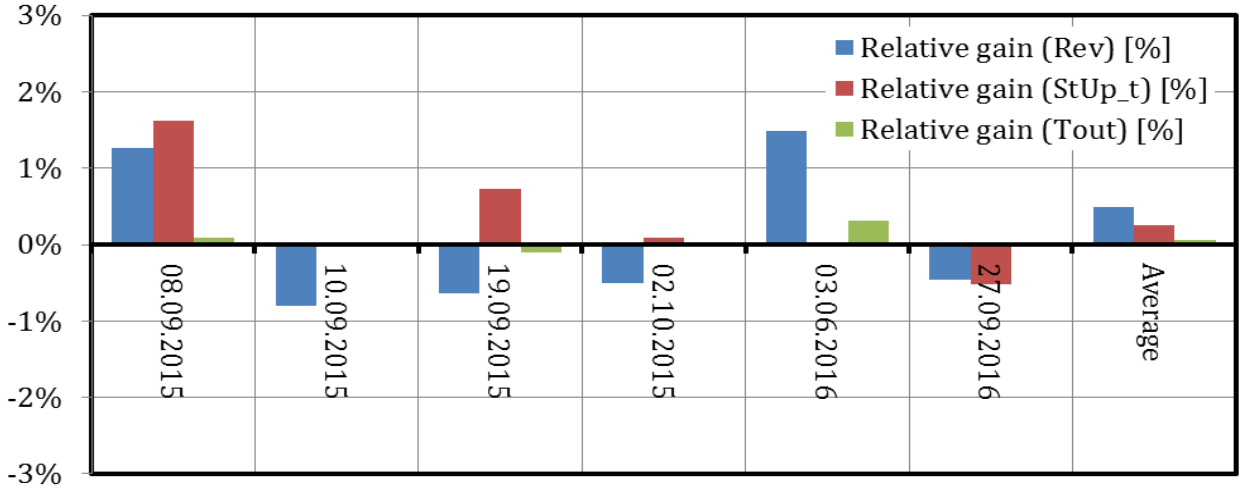
- Nowcasting system provides information of the spatial distribution of shadows on the solar field.
- A controller provides suitable flow rate to improve the yield and stabilize the temperature during cloud passage.
- Investigation of **normal operation** show revenue increase of approximately 1% for 20 investigated days.



	WD1	WD2	WD3	WD4	WD5
Gain	2.24 %	0.03 %	1.71 %	0.7 %	2.22 %

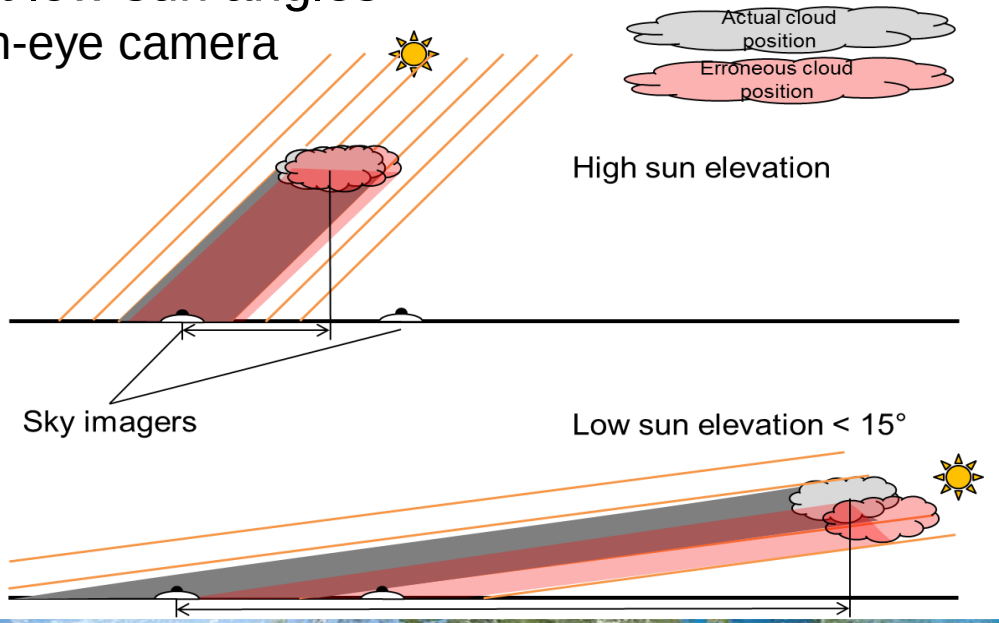
Potential benefit during start-up

- 17 days in total:
  - Increase in revenue for only 2 days
  - On average of 17 days:
    - 0.38% increase in revenue.
    - ~0.2% reduction in start-up time



Challenges for nowcasting system during start-up

- Thinking about advanced control concepts.
- Reduction in system accuracy at low sun angles
  - Clouds in the horizon of the fish-eye camera
  - Errors in shadow projection

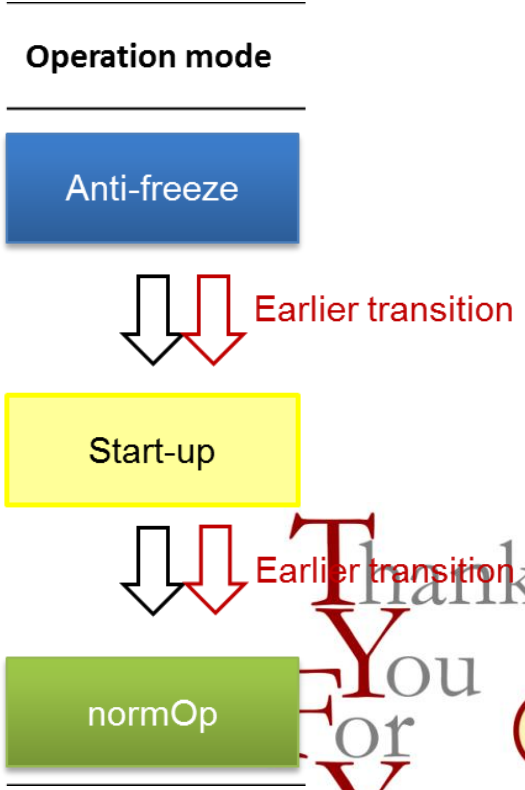


Summary and conclusions

- Physical behaviour of a solar field during start-up is modelled.
- A modified control concept based on nowcasting system is programmed.
- Economic benefit during start-up can be evaluated.

Outlook

- More advanced control based on model-predictive methods.
- Using short-term forecasts to make the solar field more proactive to disturbances.



Thank You For Your Attention